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STRATEGY RESEARCH PROJECT

CALIBRATING EXPECTATIONS: THE BENEFITS AND THE LIMITATIONS OF MODELS AND SIMULATIONS IN THE ACQUISITION PROCESS

BY

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Calibrating Expectations: The Benefits and the Limitations of Models and Simulations in the Acquisition Process

by

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U.S. Army War College CARLISLE BARRACKS, PENNSYLVANIA 17013

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ABSTRACT

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The Army is committed to exploiting the benefits of modeling and simulation (M&S) to improve the acquisition process. M&S is expected to simultaneously support the goals of "faster, better and cheaper." M&S will enable continual involvement of the user in requirements evolution, will reduce cycle-time by means of more efficient development processes, and will lower the ultimate cost of ownership by addressing all aspects of sustainability early in a program. Army interest is motivated and sustained by the ever-increasing availability of enabling technologies for M&S, by examples of successful implementations of virtual prototyping in commercial industry, and by impressive displays of virtual-reality and special effects by the entertainment industry. These developments suggest that a bold new strategy for virtual design and development is "on the horizon." However, models and simulations are inherently limited in what they can do, i.e., by their very nature they only approximate reality. Moreover, the fundamental management constraint embedded in simultaneously addressing cost, schedule and performance, i.e., a program manager can reasonably set only two of the three, suggests there are limits to what can be accomplished. For all these reasons, M&S should be an essential tool for a PM to improve his program, but it should not be expected to be a panacea for all program challenges nor should a single M&S approach be expected to fit all program needs. The purpose of this research is to determine reasonable expectations of potential M&S contributions to the acquisition process and to propose focus areas for the Army M&S community in order to maximize the benefits to the acquisition community.

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I also wish to specifically cite the staffs of the Center for Professional Development and Training and the Institute for Advanced Technology for the assistance provided in preparing and formatting this paper. Especially noteworthy was the library research guidance and assistance provided by Noah Lowenstein and the graphics assistance from Cheryl Rae.

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CALIBRATING EXPECTATIONS: THE BENEFITS AND THE LIMITATIONS OF MODELS AND SIMULATIONS IN THE ACQUISITION PROCESS

INTRODUCTION

There is a tide in the affairs of men, which, taken at the flood, leads on to fortune; omitted, all the voyage of their life is bound in shallows and in miseries

-William Shakespeare

The great bard's view of lost opportunity from his play *Julius Caesar* is almost as appropriate to the subject of this paper as is the old adage, "Opportunity knocks but once," with one important distinction. Even though the Army is still pursuing a simulation-based approach to acquisition, it still has the opportunity to exploit models and simulations (M&S) in the acquisition process just as the visionaries of the early 1990's described. The potential benefits of M&S are forever nearing Shakespeare's "flood stage", and the opportunity to exploit them will continue to knock; it's only a question of when or if we'll open the door.

EARLY EXPECTATIONS

Interest in simulation exploded in the late 1980's and was driven in part by the concept of distributed simulation as embodied in the Defense Advanced Research Projects Agency (DARPA) Simulation Networking (SIMNET) program. In the truest sense of the phrase, SIMNET enabled a paradigm shift in how training could be conducted. Instead of assembling soldiers for live training, SIMNET enabled troops in geographically-dispersed units, to use manned simulators in dynamic, free-play exercises on a virtual battlefield. Moreover, The visual nature of SIMNET captured the imaginations of many inventive people and stimulated a host of innovative applications.

The SIMNET-inspired, distributed-simulation paradigm seemed to be all things to all people at the same time. The vision depicted in Figure 1 was perhaps the most elegant description of the ultimate end-state if the concept were carried to its natural conclusion. It shows individual, discipline-specific M&S capabilities - each of which are valuable tools in their

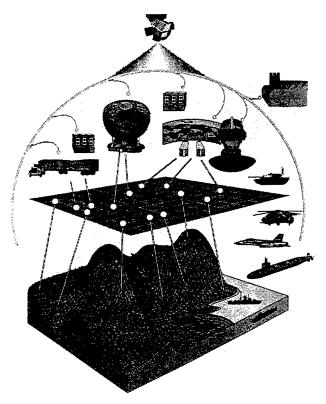


FIGURE 1 SIMULATION VISION

own right - interconnected via the internet to achieve far greater effect than each could alone. In the training arena, distributed simulation held forth the vision of large-scale training exercises that were lower cost, safer and which could be conducted without damage to the environment. Simulators were to be inexpensive enough, i.e., less than \$250k, that SIMNET sites could be populated throughout the active and reserve components. In the operational world, distributed simulation was to enable planners to rapidly generate terrain databases of the

latest trouble spot, to conduct mission rehearsals, and to evaluate proposed courses of action. Soldiers could rehearse their missions en route and in staging areas prior to the start of their mission. The simulation would be all the more realistic because the computer-generated opponents would be programmed to fight with the tactics of the expected adversary. Even better, the threat would be "dialable", that is, it could behave like Soviet forces one moment and Iraqi troops the next. Developers, who previously promoted "fly before you buy" so that users could evaluate products in hardware prototypes before purchasing them, now proposed to employ distributed simulation to provide users with yet another level of risk reduction. Users could simulate before they "flew" by shaking out concepts on the virtual battlefield before metal

was even bent on a prototype. Real visionaries spoke of true "virtual prototyping," a process in which all development was performed in simulation and the very first instance in hardware would be a production item ready for fielding. At nearly the same time, commercial Industry made great strides in applying virtual prototyping techniques to substantially improve their design and development processes. Most notable was the Boeing Corporation development of the Boeing "777" airplane which was done almost entirely by using computer models and representations.

There was a host of reasons to expect that a new approach to training and equipping the force could be facilitated by distributed simulation. While the computer capabilities of the time did limit performance, there seemed to be no technical obstacles to achieving the goal of a more efficient and a more cost-effective procurement process. Admittedly, the simulation technology incorporated in early SIMNET was crude, especially by today's standards, but it was remarkably effective and was improving all the time. Moores' Law,2 "Every eighteen months, processing power doubles while costs hold constant," legitimized the belief that technological immaturity was only a near-term barrier to success. Command emphasis on the use of M&S from the Chief of Staff, Army, downward was rampant. Simulation Master Plans became part of a program manager's requisite planning process. Defense and Service simulation offices were created. Engineers and scientists demonstrated natural extensions of the philosophy of concurrent engineering by interconnecting engineering design tools in a distributed-simulation paradigm³ and by analyzing design concepts with an operator directly in the design loop⁴. Metcalfe's Law, "The utility of a network increases with the square of the number of users,"5 hinted at the cumulative synergistic effect of widespread collaboration in distributed simulation. Resources were available. Commercial industry proved that it could be done; everyone just knew the Army could do it too. The only open question was just how successful the Army would ultimately be. Yet a decade later, the vision is still unfulfilled.

EARLY CHALLENGES AND MISSTEPS

A candid assessment points to a number of reasons for the Army's failure to achieve the goal.

Exaggerated schedule and performance claims by supporters about M&S capability to do everything "faster, better and cheaper" eroded confidence. Unreasonably inflated expectations of M&S customers, many of which were not met, caused resentment in the field and a reassessment of what was really doable in the near-term. This author can testify from personal experience as the final SIMNET Program Manager about the extreme disconnect between user expectations and what was actually deliverable under the SIMNET contracts.

Furthermore, concerns about the inherent limitations of M&S as well as the inappropriate use and the potential abuse of M&S in analyses heightened the awareness of the operations-research community. These concerns as well as the test community's objection to testing in simulation instead of hardware served to drive M&S progress to a more measured pace.

Declining resources, during the draw-down of forces in the early 1990's, coupled with an unrealistically optimistic estimate of the true cost of implementing almost all parts of the vision, caused a reassessment of M&S priority in the budget process. Simultaneously, cost-reduction initiatives began to shift the focus of M&S into a cost-savings tool.

Finally, in this author's view, the most important reason that a simulation-based procurement process is still "on the horizon" is that the Army lacked an overarching vision which could focus the contributions of all M&S participants toward a common goal. The Army and Department of Defense vision statements^{6,7} speak broadly in terms of interoperability of models, of open architecture, and of integrating M&S tools into the acquisition process. However, the bulk of acquisition simulation is performed within individual program offices, and such high-level goals are beyond the resources and the charters of most program managers. As a result, M&S literature is rife with success stories that were program-specific^{8, 9, 10, 11} but which were not

generally applicable to the wider user community. A lot of good M&S work, by intelligent and dedicated professionals, advanced individual program-office goals but was so compartmentalized that the corporate Army and the Defense Department was unable to exploit the synergy of their efforts. Neither was the Army able to formally incorporate the individual program-office M&S efforts into the acquisition process.

The puzzling thing is that the various visions proposed by the trainers, operators and developers are still as desirable today as they were when they were first surfaced 10 years ago; it would be difficult to state them any better. Moreover, technology has advanced as predicted and techniques have improved accordingly. Failure in the face of such progress begs the question, "Why aren't we there yet?"

LIMITATIONS

Analysts write about war as if it's choreographed ahead of time, and when the orchestra strikes up and starts playing, everyone goes out and plays a set piece. What I say to these folks is, "Yes, it's choreographed, and what happens is the orchestra starts playing, and some SOB climbs out of the orchestra pit with a bayonet and starts chasing you around the stage, and the choreography goes right out the window."

—GEN Norman Schwartzkopf

The Commanding General of Allied Forces during Operation Desert Storm made this comment at a press briefing in response to a reporter's question about the conduct of the operation. GEN Scwartzkopf's answer vividly captures the essence of the fog of war and points to perhaps the most fundamental challenge for military planners – the inherent unpredictability of warfare. When one also considers the approximate nature of even the best models, the challenge to the M&S community is even more daunting.

UNKNOWNS AND UNKNOWN UNKNOWNS

All models are approximations to reality and have limited ranges of validity. Dr Solomon W. Golomb, Professor of Communications at the University of Southern California, summarized limitations and pitfalls of using models and simulations in the form of "Ten Commandments" as shown in Table 1.¹²

I Thou shalt not believe the 33 rd order consequences of a first order model.	VI Thou shalt not limit thyself to a single model - more than one [model] may be useful for understanding different aspects of the same phenomenon.
II Thou shalt not extrapolate beyond the regions of fit.	VII Thou shalt not retain a discredited model.
III Thou shalt not apply any model until you understand the simplifying assumptions on which it is based and can test their applicability.	VIII Thou shalt not fall in love with thy model.
IV Thou shalt not believe that the model is reality.	IX Thou shalt not apply the terminology of Subject A to the problems of Subject B if it is to the enrichment of neither.
V Thou shalt not distort reality to fit the model.	X Thou shalt not expect that having named a demon thou hast destroyed him.

TABLE 1 TEN COMMANDMENTS OF MODELS AND SIMULATIONS

Analysts familiar with M&S literature, especially those who maintain contacts through the various professional M&S conferences, have most likely seen similar expressions of guidance on the use of models. For the most part, these guidelines are self-explanatory, and like Murphy's proverbial laws, one can often relate them to his personal experience. Insofar as this author has been able to determine, Dr Golomb's final two commandments are unique to him but make a valuable point. With respect to commandment number 9, Dr Golomb adds, "The purpose of terminology and notation should be to enhance insight and facilitate computation — not to impress the uninitiated with gobbledygook." Together with the final commandment, it serves as both a warning to the modeler and as counsel to decision-makers; the burden of explanation of the results, method and assumptions rests with the modeler.

Unknowns, or as they are sometimes referenced "unks," are the bane of the modeler. Modelers must often estimate the effects of variables they cannot otherwise accurately measure or characterize. Examples include the effects of degraded performance caused by fatigue and by stress. Coincidentally, both are good examples of Dr. Golomb's 10th Commandment; having named a section of code "degraded performance" does not necessarily mean that true effect has been captured. As troubling as unknowns may be, even more troubling are the unknown unknowns or "unk unks," those variables which affect an analysis but of which the modeler is completely unaware. "Unk unks" often surface when subsystem models are combined to represent an aggregate system. Interrelationships among subsystems, which had not been anticipated by the individual subsystem-modelers, become painfully apparent when the overall system-model behaves inappropriately. Usually, this is accepted as a cost of doing business, and modelers resign themselves to the fact, "You don't know what you don't know." Bran Ferren, President for Research and Development, Creative Technology at Walt Disney Imagineering extended this line of reasoning to astonishing effect. He observed that there are cases of commonly-used applications which cannot be and most likely will never be understood by any one person.¹⁴ He cited the Windows™ operating system for personal computers as an example. Teams of individuals may be identified who collectively possess the understanding of how Windows™ operates, but no single individual is capable of comprehending all aspects of the software. Extending the modeler's assessment of "unk unks," one must conclude, "Not only do we not know what we don't know, we don't even know what we do know." 15

Dr. LaBerge, a former Under Secretary of the Army, suggests one key way to substantially improve the capability for M&S to support the decision-making process is to implement peer review of M&S results.¹⁶ He convincingly argues that the goals of verification, validation and accreditation (VV&A) are better served by the peer-review process of scientific research practiced in the academic environment. Just as articles submitted for publication in

refereed journals undergo peer review, so should the results of modeling and simulation. Decision-makers cannot be expected to verify correctness or applicability of M&S claims, and the current VV&A process only authenticates methodology, not results. This recommendation is especially attractive because of its potential for better-informed decisions and because of the ease with which it could be implemented within the framework of networked M&S experts depicted in Figure 1. Peer review would also address concerns that the current VV&A process is expensive and not well understood¹⁷ and help to reduce the number of unknowns in the analysis.

OUTSIDE INFLUENCES

No discussion of the limitations of M&S would be complete without recognizing that outside influences, such as emotion, mistrust, and hidden agendas, can adversely influence decisions even if a simulation is well planned and well run.

Consider the circumstances surrounding the simulation of the final day of the siege of the Branch Davidian compound by FBI agents in Waco in April, 1993.¹⁸ At issue is "... whether the FBI is being truthful about its role in the standoff at the Branch Davidians' Mount Carmel compound before it burned to the ground on April 19, 1993."¹⁹ Lawyers representing survivors of the siege in a wrongful-death suit against the Government maintain that the FBI fired weapons into the compound before it erupted into flames and cite as evidence repeated flashes recorded by airborne, infrared cameras which were flown by the FBI over the compound that fateful day. The FBI denies that its agents shot into the compound on the day of the fire. A reenactment at FT Hood was intended to answer any lingering doubts. Two aircraft using the same cameras as were employed during the actual siege photographed a team of soldiers and postal inspectors as they executed a series of drills and fired weapons. Analysts expected that the film taken during the reenactment would indicate whether the unexplained flashes cited by

the plaintiffs' lawyers were the result of FBI gunfire or could be explained by other factors such as reflections from surface water or other debris. Unfortunately for those hoping for a speedy explanation, the videos have been sealed instead of being released to the public. This action, taken by a U.S. District Court judge, led at least one reporter to observe, "The lack of public access creates the possibility that both sides in the case will release conflicting opinions without any public viewing of the videos." True to the reporter's prediction, on the very next day, lawyers for both the Government and the plaintiffs claimed that the videotape conclusively supported their respective positions. Four days later, both parties acknowledged that better copies of the videotaped reenactment would be needed before their experts could make a determination.²¹

It is not my intent to judge the actions of the parties involved; this case is cited because of its national interest and to highlight several complicating factors. The plaintiffs' case was motivated by mistrust of the Government's account of events during the siege. Under the circumstances, it's unlikely that the results of the simulation would be accepted unless they conclusively answered the question or at least supported the plaintiffs' position. Considering the conflicting claims made by experts viewing the same data, the only thing one can safely conclude is that at least half of the experts are wrong. The judge's actions, to first close the simulation to key personnel and then to seal the results, highlights the importance of concerns beside just getting to the facts of the case. No matter how carefully the reenactment was planned and executed, the usefulness of the simulation in such an atmosphere of mistrust was doomed to failure.

Now consider the rationale behind the preference of the F-22 Program Office for using modeling and simulation instead of hardware tests to predict the performance of its aircraft. "Modeling and Simulation offers the F-22 program another benefit, Air Force sources said, because the Service would control the inputs into the model, the outcome – proving the aircraft's effectiveness – is much easier to shape than the outcome of an open air test with any

number of unanticipated variables."²² Clearly insightful use of M&S allows one to get the answer he "knows is right." Is it any wonder the test community strenuously mistrusts and opposes the practice of test and evaluation in simulation? "We have no evidence to show us that you can substitute modeling and simulation in the live fire world for live fire tests."²³

Lack of trust among acquisition professionals was also one of the issues cited in an early assessment of M&S in acquisition.²⁴ Specifically, the study recognized that program offices overly control access to their system models to prevent their misuse, i.e., evidence of mistrust of those outside the program. The study also cited program office concerns that their programs might be subject to side-by-side comparisons and trade-off analyses with competing programs and hence an unwillingness to participate if the results were unlikely to be favorable.

POTENTIAL

The more you know, the harder it is to take decisive action. Once you become informed, you begin seeing complexity and shades of gray. You realize that nothing is as simple as it first appears. Ultimately, knowledge is paralyzing. Being a man of action, I can't afford to take that risk.

—Calvin [of Calvin & Hobbes]

PERFORMANCE

One "commonly known fact" is that how well a system is designed will determine how much it will cost to sustain it. One source on simulation for acquisition quantifies the amount in the terms, "70 to 90 percent of [a system's] life cycle funds are committed in the first 10 to 30 percent of the life cycle." If this is true, and it generally is accepted as such, then M&S efforts must focus on the early design and development stage of a program if it is to produce the greatest cost and performance benefits. The practice best suited to promote this early involvement is concurrent engineering, "a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support ... considering all elements of the product life cycle from conception through disposal, including

quality, cost, schedule and requirements."²⁶ M&S promotes collaboration among discipline-specific experts and facilitates the exchange of design information among a multi-disciplinary team.

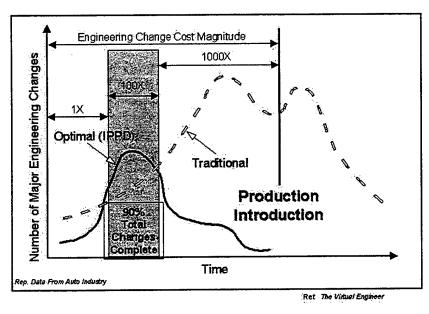


FIGURE 2 COST OF ENGINEERING CHANGES

In an often-cited reference for automotive industry, The Machine That Changed The World: The Story of Lean Production, the authors argue that the four elements of lean design are leadership, teamwork, communication, and simultaneous development.²⁷ These

elements are equally appropriate in the context of military acquisitions, and M&S is the ideal means to facilitate all aspects of the process. The authors maintain that collaboration among a multidisciplinary design team, in which ideas are openly exchanged and resolved at the team level, and specific consideration of all aspects of the production and fielding process are essential for efficient product development. Intuitively, their argument makes sense and even though they avoid many of the commonly used terms, their statement captures the essence of the concepts of Integrated Product Teams (IPT), Integrated Product Development (IPD), Integrated Product and Process Development (IPPD) and concurrent engineering. In this respect, M&S provides the ideal mechanism to facilitate all four elements.

Specifically, simultaneous development is credited with the following benefits²⁸:

- 1. Improving the quality of designs, resulting in dramatic reductions of engineering change orders (greater than 50 percent) in early production.
- 2. Reducing product development cycle time by as much as 40 to 60 percent through concurrent, rather than sequential, design of product and processes.
- Reducing manufacturing costs by as much as 30 to 40 percent by having multifunction teams integrate product and process designs.
- Reducing scrap and rework by as much as 75 percent through product and process design optimization.

A substantial portion of the M&S cost benefits arise from early resolution of design problems.

Figure 2²⁹ clearly illustrates the relatively lower cost of engineering changes as well as their fewer number when comparing a traditional, serial approach to development with a concurrent engineering approach to development.

If the assessment of concurrent engineering is not attractive enough from a cost efficiency perspective, it cements its credibility with the observation that proper implementation of a concurrent-engineering approach requires, "early consideration of a product's manufacturing and support processes while shaping the *user's* [emphasis added] requirements" into the design.³⁰ The user's requirement drives the military acquisition process, and it plays an even larger role in the case of spiral development. A collaborative approach to product development that includes the user is far more likely to succeed than one that does not actively seek user input. M&S affords the user an opportunity to participate directly throughout the entire design process and to do so with tools that exploit his subject matter expertise, like reconfigurable, man-in-the-loop simulators.

The mental picture the reader should have at this point is that of a soldier subject-matterexpert fighting a weapon system concept on the virtual battlefield and evaluating all aspects of performance from man-machine interface to combat effectiveness. Simultaneously, engineers from all design disciplines evaluate the ability of the design to perform under the loads and stresses imposed by the soldier in the loop. All designers, the soldier included, examine a common concept of the product from their own unique perspective, using tools best suited for their discipline, and participate in improving the design.

Several NASA web sites^{31, 32} offer insight into the various design perspectives that should be considered in the design process. These are summarized in Table 2.

Evaluability	Marketability	Designability
Testability	Producibility	Deployability
Supportability	Evolvability	Retireability
Value	Competitive Advantage	Quality
	Testability Supportability	Testability Producibility Supportability Evolvability

TABLE 2 NASA "DESIGN FOR ..." CONSIDERATIONS

The NASA listing is by no means all-inclusive and is noteworthy both for items it includes and for items that are glaringly absent. Designers of Army systems must consider a wide range of additional perspectives. A suggested list is shown in Table 3.

Lethality	Survivability	Transportability	Reliability
Disposability	Maintainability	Assembly	Disassembly
The Environment	Safety	Durability	Affordability

TABLE 3 ARMY "DESIGN FOR ..." CONSIDERATIONS

This author's list is not comprehensive either, and the adage, "Where you stand depends on where you sit," applies should one try to prioritize the importance of these design considerations. In an age of specialization, it is expected that experts will skillfully argue their

cases from their own unique perspective. However, depth comes at the expense of breadth, and whatever the experts gain in their own field, they lose in appreciation and understanding of others. Specialization increases the tendency toward parochialism in presenting one's case. It calls to mind the engineering posters that were prevalent in the early 1980s that showed a product design as seen by the various contributing disciplines. For example, the tank, as seen by the armaments engineer, showed an inconsequential tracked vehicle sporting a comically large main gun. The tank, as seen by the suspension engineer, depicted all aspects of trafficability, e.g., springs, road wheels, etc., as being grossly larger than all other aspects of the design. Usually such posters contained a final picture, that as seen by the user, which represented a well-thought-out answer. The fact that these posters were popular at all suggests that even among professionals, there is the danger of parochialism.

M&S serves as a means to promote communication among the design disciplines.

Teaming serves as a filter to built-in bias. Properly implemented, IPTs will weigh the benefits of competing design ideas and resolve them at the team level without resorting to management direction. Even so, there is a danger that management will be swamped with information and trade-off decisions. However, considering that the alternative is "hiding one's head in the sand" and relying solely upon inputs from a select group, more knowledge is better. The opening epigraph from Frank Watterson's now-retired comic strip <u>Calvin and Hobbes</u> makes the point clearly.

COST AND SCHEDULE

... although the technical problems had been recognized early enough to prevent the [Challenger Space Shuttle] disaster, meeting flight schedules and cutting costs were given a higher priority than safety.

—U.S. House of Representatives Committee on Science and Technology³³

Any discussion of M&S potential would be incomplete if it did not address cost and schedule, and much can be learned from examining NASA's experience. NASA's efforts in

M&S are often highlighted as shining success stories for the military to emulate. They deserve closer review especially since NASA program managers face the same cost, schedule, and performance demands as do military program managers. Several NASA failures, in face of these demands, have called into question the validity of the "faster, better, cheaper" philosophy.

When the space shuttle Challenger exploded shortly after lift-off, and the whole sevenperson crew was killed in front of a national television audience, both the President and the Congress began immediate and wholesale investigations to determine the cause and to effect measures that would prevent it from happening again. The Rogers Commission, charged by the President with assessing the accident, determined that the incipient physical cause of the Challenger disaster was "... the destruction of seals ['O' rings] that are intended to prevent hot gases from leaking ... during propellant burn." 34 The report describes the sequence of events resulting from the decision to launch the Challenger in the cold early morning hours of January 28, 1986. In the near-freezing temperatures, the 'O' rings were not sufficiently pliable to seal the solid rocket booster joint and prevent the escape of hot gasses after launch. The resulting leak of flame and hot gas from one of the booster rockets weakened the strut that attached the booster to the external fuel tank. Within seconds, the strut failed and the booster slammed into the shuttle wing and the external tank causing the explosion. Engineers had previously surfaced concerns about the 'O' rings and also highlighted the potential danger of launching in cold weather on the day of the flight, but their concerns were overruled in favor of meeting NASA's demanding flight schedule — 15 missions in calendar year 1986. The Rogers Commission specifically faulted the management structure of both the prime contractor, Thiokol, and that of NASA for not allowing critical information to reach the right people.³⁵ Congress' assessment in the opening epigraph was much more pointed and far more suggestive of the pressures NASA engineers must have faced. Overemphasis on cost and schedule was the ultimate cause of the explosion; the failed seals were just a symptom.

The climate created by the administration's demanding cost and schedule requirements is similar to the one that currently exists in NASA under the "faster, better, cheaper" philosophy of product development. Moreover, the effects are as clear today as they were at the time of the Challenger disaster because NASA suffered the loss of all Mars' spacecraft in the last year. The physical causes of the failures can be as easily explained as the cause of the Challenger explosion. The Mars Climate Orbiter was lost because "... contractor Lockheed-Martin's Mars team forgot to convert from English to metric units and NASA engineers failed to catch the error."³⁶ As a result, the orbiter approached Mars at the wrong altitude and was lost in space. NASA engineers postulate that the Mars Polar Lander was lost because of a single, missing line of computer code.³⁷ Without the proper coding, the Lander mistakenly "thought" it had safely landed on the surface and prematurely shut down its braking thrusters while it was still 130 feet above the surface. It was most likely destroyed upon impact. The fate of two piggy-back probes is still uncertain. The explanation for the loss of the Polar Lander is only an engineering, best guess. Telemetry, which would have communicated the Lander's condition during descent into the Mars atmosphere and would have conclusively explained the cause, was eliminated as a cost-saving measure earlier in the program.

"Faster, better, cheaper" will most likely be forever seen as a dictum to "do more with less." NASA investigations of the failures concluded that the Mars projects were "underfunded, understaffed and over stressed." The investigation observed that managers, against their better instincts, may have failed to raise their concerns for fear of losing ground in competition for tight funding. NASA's top scientist, Edward Weiler, acknowledging the fundamental flaw of the "faster, better, cheaper" philospohy stated, "We've found the boundary." ³⁹ Implicit in his assessment is that the effects were unacceptable and counterproductive to the goal of increased efficiency.

"Faster, better, cheaper" is often heard in military acquisition circles, but almost all program mangers privately scoff at the logic behind it. Instead they adhere to the 'Management

101" adage concerning cost, schedule and performance, i.e., "You can only pick two of the three." Figure 3 illustrates the inherent interrelationship of cost, schedule and performance in terms of a feasibility space or trade space. It simplistically illustrates the interdependence of the variables and clearly shows that the manager only has the freedom to control two of the three variables, e.g., by fixing performance and schedule, one has no flexibility in varying the cost. The trade space is proposed as a means to identify options in the development process. Each point on the surface represents a material solution which can be evaluated based upon

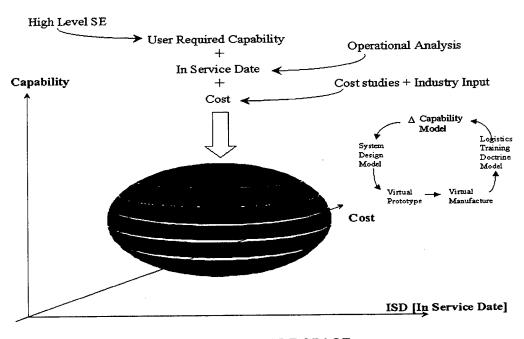


FIGURE 3 TRADE SPACE

performance needs, budget constraints, and required timeliness of delivery. In practice, the trade space would not be anywhere near so smooth nor so well behaved as the ellipsoid suggests; it would most likely be irregular and discontinuous. Moreover, it would be a significant exercise to define the whole trade space for any reasonably complex system. Still, M&S can be effectively used to populate the trade space with at least some of the options so that leadership can make more-informed decisions.

If NASA's successes motivated the Army to strive for similar gains, then NASA's failures should similarly motivate the Army to at least re-examine its policies and its preoccupation with near-term cost savings in defining expectations for M&S. Figure 2 clearly demonstrates the cost efficiencies associated with early detection and correction of design deficiencies. However, design changes do require resources, both time and funding, to implement. The benefits, which are realized from the design change, are categorized as cost avoidance, while the expense incurred for the change is a true cost. To put things in perspective, consider the engineering change implemented by the Family of Medium Tactical Vehicles (FMTV) program office to correct a design flaw that caused excessive vibration in the drivetrain at highway speeds. Since the engineering change was implemented during production and after some vehicles had been fielded, the FMTV program incurred costs that were at least an order of magnitude higher than would have been incurred had the flaw been detected and fixed before production began. However, if the flaw had been detected earlier in the program, the resulting expense and time to implement the fix might have been categorized as cost growth and schedule slip, the two things NASA managers feared most in the Mars program. Cost and schedule must be viewed from the perspective of the overall, system life-cycle if models and simulations are ever to truly change the acquisition process.

RECOMMENDATIONS

This author recognizes that any discussion of the use of M&S in the acquisition process is moot. Models and simulations are inextricably linked to the engineering, science and analytical professions that are responsible for developing and fielding military hardware. In spite of their limitations, models and simulations are powerful tools for improving the decision-making process. The only open question is, "Can these tools be more effectively exploited in the acquisition process?" With that goal in mind, I propose the following recommendations:

- 1. Focus modeling and simulation efforts on Army applications that specifically advance the CSA's vision for transforming the Army. The Program Manager, Future Combat System (FCS) should establish an M&S milestone to evaluate design concepts. Concurrently, TRADOC should develop the scenarios. It should be noted that the FCS solicitation⁴¹ addresses many of the points raised in this paper, i.e., simulation-based approach, teaming, etc. The benefits of establishing a simulation milestone to the FCS schedule would be to focus many related efforts, e.g., simulation interoperability, subsystem modeling, etc, and to provide a needed sense of urgency in the M&S community.
- 2. Adopt a vision statement that evokes the mental picture suggested in Figure 1, and encourage program managers to contribute to the vision by extending their program-specific M&S efforts for more general use. The bulk of M&S efforts are performed in individual program offices; with proportionately little extra resources, these simulations can be made to be more general purpose, especially if a program manger begins a simulation effort with wider use in mind. To do that, however, he must have a clear picture of what is expected. Current vision statements leave too much room to conclude that it's someone else's responsibility.
- 3. Incrementally and formally incorporate mature modeling techniques (low, hanging fruit) into the acquisition process beginning with the transportability and deployability-analysis tools maintained by the Military Traffic Management Command,
 Transportation Engineering Agency. These tools are low risk, mature, proven, and are directly applicable to the Chief's transformation vision. Benefits would be twofold: first, formal recognition of this capability would reduce the likelihood resources would

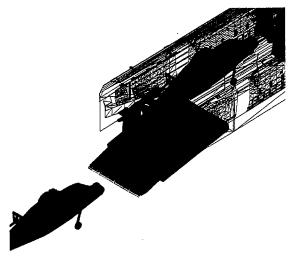


FIGURE 4 TRANSPORTABILITY ANALYSIS

be spent elsewhere, duplicating this capability, and second, these tools could "proof" the process by which other models are incorporated into the acquisition process. The learning curve has to start somewhere.

4. Implement and accept a peer-review alternative to the current VV&A process for authenticating M&S results. Peer review is a natural outgrowth of the collaborative

engineering approach using distributed simulation and modeling tools. Place the burden for explanation and support of results with the modeler, and recognize that the primary benefit of M&S is risk reduction (not risk elimination) resulting from extensive collaboration among experts from all aspect of the acquisition process.

Develop and track appropriate metrics. Begin with life-cycle cost. The NASA
experience has demonstrated the fallacy of "faster, better, cheaper," and its focus on
near-term savings.

CONCLUSION

... convergence has meant two things: the coming together of the computer, consumer electronics, and telecommunications industries and the merging of gadgets such as the PC, TV and telephone. But this is only the start. Combine digital technology with advanced software, smaller and more powerful microprocessors, and exponential growth in fiber and wireless bandwidth, and you get something far more useful — seamless, universal connectivity. ... Call it "virtual" convergence — everything you want in one place, but that place is wherever you want it to be.

-Bill Gates⁴²

Simulation Growth

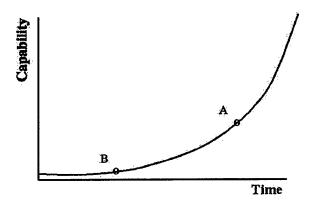


FIGURE 5 SIMULATION GROWTH

From his position as President for Research and Development at Walt Disney Imagineering, Mr. Ferren has a unique perspective on evolving technologies. He vividly described the potential for M&S to modernize the

acquisition process in terms of the exponential curve in Figure 5.⁴³ He then asked the audience attending the most recent Simulation and Modeling for Acquisition, Requirements, and Training conference where they believed the Army was on the growth continuum. Most of the audience, having witnessed the many changes precipitated by M&S over the last decade, pointed to a point on the "knee" of the curve, i.e., Point A. Mr. Ferren disagreed. He emphasized that we have barely "left the gate" in the computer revolution and that the audience had better adjust its reference to a point nearer to Point B because the greatest rate of change is yet to come.

At the same conference, a panel of General Officers was asked why, after a decade of pursuing the vision of a simulation-based acquisition process, are we not "there" yet. MG John Caldwell, currently the Commanding General of the U.S. Army Tank, Automotive and Armaments Command, attributed it to a lack of focus. ⁴⁴ He likened the situation to a group of talented engineers, who in the absence of specific direction, tend to work only on problems that interest them. He further commented that the answer is to provide them direction, and that in the case of M&S, it should be to focus efforts in support of the Chief's Transformation Vision.

The opening epigraph describes the concept of convergence and the potential that results from combining technologies. Those pursuing the M&S vision stand at a crossroads where technology, need, and interest converge. M&S tools have improved dramatically over the last decade. The need to transform the Army into a more deployable force has become the Army's top priority and represents an ideal opportunity to use M&S to advantage. Interest in

applying ever more capable M&S tools to revamp the acquisition process is as high as it has ever been. The Army has the means, the desire and the motivation to succeed. Will the question, "Why aren't we there yet?" be asked again a decade from now?

ENDNOTES

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- ³ E.J. Haug et al., "Virtual Prototyping Simulation for Design of Mechanical Systems," <u>ASME Journal of Mechanical Design</u> V117(B) (June 1995): 65.
 - ⁴ Ibid., 64.
 - ⁵ Downes and Mui, 24.
- ⁶ Department of the Army, Office of the Deputy Chief of Staff for Operations and Plans, <u>The Army Model and Simulation Master Plan</u>, (Washington, D.C.: Army Model and Simulation Office, October 1997), 2-3.
- ⁷ Defense Modeling and Simulation Office, "Department of Defense Modeling and Simulation (M&S) Master Plan," October 1995; available from http://www.dmso.mii/documents/policy/msmp/index.html; Internet; accessed 8 December 2000,

ch. 2.

- ⁸ Albert B. Garcia, Robert P. Gocke, Jr, and Nelson P. Johnson, <u>Virtual Prototyping:</u>
 <u>Concept to Production</u> (FT Belvoir, VA: Defense Systems Management College Press, 1992), 45-132.
- ⁹ Lalit K. Piplani, and Joseph G. Mercer, and Richard O. Roop, <u>System Acquisition</u> <u>Manger's Guide for the Use of Models and Simulations</u> (FT Belvoir, VA: Defense Systems Management College Press, 1992), ch. 8.
- ¹⁰ Michael V. R. Johnson, Mark F. McKeon, and Terence R. Szanto, <u>Simulation Based Acquisition</u> (FT Belvoir, VA: Defense Systems Management College Press, 1998), ch. 3.
- ¹¹ Anne Patenaude, "Study on the Effectiveness of Modeling and Simulation in the Weapon System Acquisition Process," Office of the Secretary of Defense Washington DC, (October 1996), sec. III.
- ¹² Solomon W. Golomb, "The Uses and Limitations of S. & M. (Simulation and Modelling)," briefing slides, Los Angeles, CA, Simulation and Modeling for Acquisition, Requirements, and Training Conference, 28 January 2000.
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- ¹⁴ Bran Ferren, Keynote Address, Simulation and Modeling for Acquisition, Requirements and Training Conference, Los Angeles, CA, 26 January 2000.
- ¹⁵ Steve Collier, untitled remarks, Simulation and Modeling for Acquisition, Requirements and Training Conference, Los Angeles, CA, 28 January 2000.

- ¹⁶ Walter Laberge, Ph. D., "Contentious Issues in Contemporary Simulation and Modeling," lecture, Austin, TX, University of Texas, 23 September 2000.
 - ¹⁷ Patenaude, 49.
- ¹⁸ Sherri Chunn, "Staging of Deadly FBI Assault Is Designed to Answer Lingering Questions," Austin American-Statesman, 19 March 2000, sec. A, p. 6.
- ¹⁹ Jim Yardley, "Video of Standoff Simulation Sealed," <u>Austin American-Statesman</u>, 20 March 2000, sec. A, p.1.
 - ²⁰ Ibid., 10.
- ²¹ "Both Sides Call Davidian Test Data Poor," <u>Austin American Statesman</u>, 25 March 2000, sec. A, p.1.
 - ²² "M&S: A Dangerous Tool?", <u>Inside the Pentagon</u>, September 1, 1995.
 - ²³ John Burt, "M&S vs. Testing," <u>Defense News</u>, 1-7 August 1994, p. 22.
 - ²⁴ Patenaude, 50.
 - ²⁵ David L. Neyland, <u>Virtual Combat</u>, (Mechanicsburg, PA: Stackpole Books, 1997) 56.
- ²⁶ Robert I. Winner et al., "IDA Report R-338: The Role of Concurrent Engineering in Weapon System Acquisition," final report, Alexandria, VA, Institute for Defense Analyses, December 1998, v.
- ²⁷ James P. Womack, Daniel T. Jones, and Daniel Roos, <u>The Machine That Changed The</u> world: <u>The Story of Lean Production</u>, (New York: Harper Perrenial, 1991), 112-117.
 - ²⁸ Winner, vi.
- ²⁹ John R. Barber, and Donald J. Merkley, "Integrated Helicopter Design Tools (IHDT)," briefing slides, Los Angeles, CA, Simulation and Modeling for Acquisition, Requirements, and Training Conference, 28 January 2000.
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- ³¹ Ed Dean and Al Motley, "Design For ...," 2 September 1996; available from http://mijuno.larc.nasa.gov/dfc/dfx.html; Internet; accessed 15 February 2000.
- ³² Ed Dean, "NASA Systems Engineering related Bibliographies," 26 July 1996; available from http://www.seas.smu.edu/disted/sys/nasabibl.html; Internet; accessed 5 MAR 2000.
 - 33 Schlager, 614.
 - ³⁴ Ibid., 611.
 - ³⁵ Ibid., 612.

- ³⁶ Kathy Sawyer, "NASA cancels Future Flights, Will Review 'Faster, Cheaper, Better' Philosophy," <u>Austin American-Statesman</u>, 29 March 2000, sec. A, p. 14.
 - ³⁷ Ibid., 1.
 - 38 Ibid.
 - ³⁹ Ibid., 14.
- ⁴⁰ J. M. Read and G. M. Pugh, "Helping Smart Procurement Work: The UK Synthetic Environment Based Acquisition Programme," briefing slides, Orlando, FL, Inter-service/Industry Training, Simulation, and Education Conference, 1 December 1999.
- ⁴¹ Marion Van Fosson, "Future Combat Systems Solicitation (Final)," 4 April 2000; available from http://www.darpa.mil/tto/fgcss/fgcssbaa.html; Internet; accessed 4 April 2000.
- ⁴² Bill Gates, "Everyone, Anytime, Anywhere The Next Step for Technology Is Universal Access," <u>Forbes ASAP</u>, 4 October 1999, 45.
- ⁴³ Bran Ferren, untitled remarks, Simulation and Modeling for Acquisition, Requirements and Training Conference, Los Angeles, CA, 26 January 2000.
- ⁴⁴ John Caldwell, MG, untitled remarks, Simulation and Modeling for Acquisition, Requirements and Training Conference, Los Angeles, CA, 27 January 2000.

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